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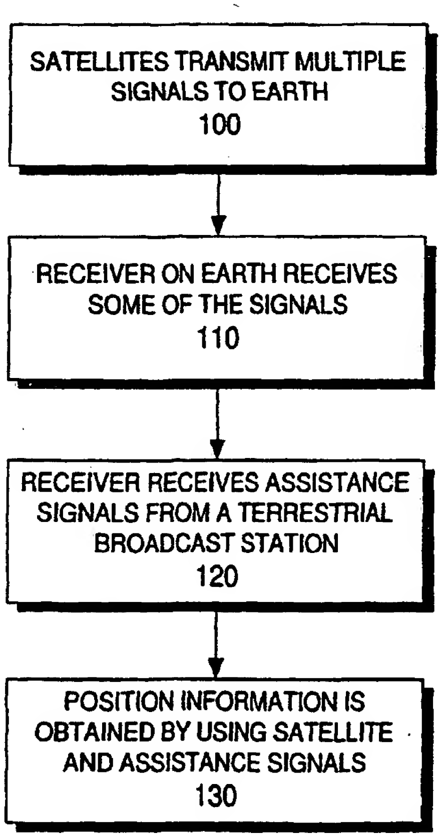
(54) Title: LOW SIGNAL-TO-NOISE RATIO POSITIONING SYSTEM



(57) Abstract: Embodiments of the present invention relate to a low signal-to-noise ratio positioning system. According to one or more embodiments of the present invention, the receiver in a conventional positioning system is configured to communicate with a terrestrial broadcast system. The terrestrial broadcast station (120) transmits assistance signals to the receiver and may be another receiver. The assistance signals enable the receiver to locate very weak signals being transmitted from the satellites in the positioning system. In one embodiment, the assistance signals include Doppler frequencies for the satellites. In another embodiment, the assistance signals include Ephemeris data. In another embodiment, the assistance signals include almanac data. In other embodiments for the present invention, the assistance signal includes navigation bits demodulated from the carrier phase inversion signal of the satellite, time synchronization signals, and pseudo range differential corrections.

WO 01/84176 A1

LOW SIGNAL-TO-NOISE RATIO POSITIONING SYSTEM

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention relates to locating the position of an object, and in particular embodiments of the present invention are directed toward using a satellite positioning system to locate the position of objects that are obstructed.

2. BACKGROUND ART

People use positioning systems to precisely determine the locations of objects. One type of positioning system is the Global Positioning System (GPS) and uses multiple satellites that orbit the earth. The satellites transmit signals to earth that can be detected by anyone with a receiver. Currently, however, it is impossible to track objects using the receiver when the object is obstructed, for instance within an enclosed structure such as a parking garage or building, or under a tree or bridge. Before further discussing the drawbacks associated with current positioning systems, it is instructive to discuss navigation generally.

Satellite Positioning System

To partially solve the problems associated with ground-based navigation systems, high-frequency radio transmitters were placed in space as part of the GPS system. As is well known, GPS was established by the United States government, and employs a constellation of satellites in orbit around the earth at an altitude of approximately 26500 km. Currently, the GPS constellation consists of 24 satellites, arranged with 4 satellites in each of 6 orbital planes. Each orbital plane is inclined to the earth's equator by an angle of approximately 55 degrees.

Each GPS satellite transmits microwave L-band radio signals continuously in two frequency bands, centered at 1575.42 MHz and 1227.6 MHz., denoted as L1 and L2 respectively. The GPS L1 signal is quadri-phase modulated by a coarse/acquisition code ("C/A code") and a precision ranging code ("P-code"). The L2 signal is binary phase shift key ("BPSK") modulated by the P-code. The GPS C/A code is a gold code that is specific to each satellite, and has a symbol rate of 1.023 MHz. The unique content of each satellite's C/A code is used to identify the source of a received signal. The P-code is also specific to each satellite and has a symbol rate of 10.23 MHz. The GPS satellite transmission standards are set forth in detail by the Interface Control Document GPS (200), dated 1993, a revised version of a document first published in 1983.

signal that identifies the satellite and provides other information. The ephemeris data provides information on the path and position of the satellite.

Current Receivers

Conventional receivers, called GPS or SPS receivers, work well when the signals travel directly from the satellite to the receiver with no obstructions in the way. When passing under trees, bridges, through garages and when the receiver is in a building, however, problems occur. Specifically, these objects present barriers that interfere with the signal and weaken it. Even worse, the navigation message, which is typically more difficult to detect than the signals, is often undetectable when there are obstructions.

Secondly, the receiver relies on detecting reflected signals. Obstructions between the signal sent by the satellite and the receiver compromise the signal path.. The signal reflects off nearby surfaces and then to the receiver. Some of these signals may be stronger than another, even though the distance the signal travels is further, depending on the reflecting surface or surfaces. This extra distance traveled by the signal can introduce errors into the distance and location calculations.

It is desirable to overcome this difficulty for a variety of reasons. First, it would be desirable to locate an object in a building in order to allow the users of positioning devices to obtain a fix and assess position-related data to access nearby services. Second, federal mandates may require the ability to locate cell phone users

SUMMARY OF THE INVENTION

Embodiments of the present invention relate to a low signal-to-noise ratio positioning system. According to one or more embodiments of the present invention, the receiver in a conventional positioning system is configured to communicate with a terrestrial broadcast station. The terrestrial broadcast station transmits assistance signals to the receiver and enable the receiver to locate very weak signals being transmitted from the satellites in the positioning system.

In one embodiment, the assistance signals include Doppler frequencies for the satellites. In another embodiment, the assistance signals include Ephemeris data. In another embodiment, the assistance signals include almanac data. Almanac data is a list of satellites that a particular receiver should be able to access currently. This prevents the receiver from searching for satellites, for instance, that are below the horizon and not currently usable. In other embodiments of the present invention, the assistance signal includes navigation bits demodulated from the carrier phase inversion signal of the satellite, time synchronization signals, base station coordinates for 1 ms ambiguity resolution, and pseudo range differential corrections.

The assistance information may be provided by a wire, a computer network such as the Internet, or it may be provided wirelessly, such as via a cellular telephone network, wireless data network, a secondary carrier on a transmitter in the commercial broadcast service (TV or AM/FM radio) or by another equivalent means. The assistance signal permits the use of a coherent decoding and the provision of needed

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects and advantages of the present invention will become better understood with regard to the following description, appended claims and accompanying drawings where:

Figure 1 is a low signal-to-noise ratio positioning system according to an embodiment of the present invention.

Figure 2 shows the use of an assistance signal according to an embodiment of the present invention.

Figure 3 shows the use of an assistance signal according to another embodiment of the present invention.

Figure 4 shows the use of an assistance signal according to another embodiment of the present invention.

Figure 5 is a digital message from a satellite to a receiver according to an embodiment of the present invention.

Figure 6 shows the use of an assistance signal according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The invention relates to a low signal-to-noise ratio positioning system. In the following description, numerous specific details are set forth to provide a more thorough description of embodiments of the invention. It will be apparent, however, to one skilled in the art, that the invention may be practiced without these specific details. In other instances, well known features have not been described in detail so as not to obscure the invention.

Positioning System Using Assistance Signals

One embodiment of the present invention is shown in Figure 1. At step 100, signals are transmitted from multiple satellites to earth. Then, at step 110, a receiver located on earth receives some of the signals. Next, at step 120, assistance signals are transmitted from a terrestrial broadcast station. Finally, position information is obtained at step 130 by using the satellite and assistance signals.

As shown at step 120 of Figure 1, assistance signals are sent from a terrestrial broadcast station to a receiver to assist the receiver in obtaining positioning information, specifically when the receiver is indoors or when obstacles are in the way. The assistance signals may have various information in them according to various embodiments of the present invention. In one embodiment, the assistance signals have Doppler frequencies for the satellites.

searching through frequency ranges to lock in on Doppler affected satellite frequencies and the obstructed receiver may immediately begin to correlate the messages in the signal.

This embodiment of the present invention is shown in Figure 2. At step 200, signals are transmitted from multiple satellites to earth. Then, at step 210, a receiver located on earth receives some of the signals. Next, at step 220, a terrestrial broadcast station that is located sufficiently near to the target receiver calculates true Doppler frequencies for the satellites. Then, at step 230, the true Doppler frequencies are transmitted to the target receiver. Thereafter, the target receiver uses the true Doppler frequencies and tunes to those frequencies at step 240, and begins correlating at those frequencies at step 250.

Ephemeris Data

In one embodiment of the present invention, the assistance signals provide Ephemeris data. Ephemeris data is data that tells the target receiver exactly where each satellite is. Knowing the location of each satellite is essential to calculating the receiver's position. Take, for instance, the case where a receiver is located indoors. Even if the receiver was broadcast Doppler information from a terrestrial broadcast station, the receiver still might not be able to obtain a positional fix because the information telling it where the satellites are was to weak to reach it.

This embodiment of the present invention is shown in Figure 4. At step 400, signals are transmitted from multiple satellites to earth. Then, at step 410, a broadcast station calculates almanac data for a target receiver. Next, at step 420, the assistance signals, including the almanac data, are transmitted from a terrestrial broadcast station to the target receiver. Thereafter, the target receiver locates the satellites indicated in the almanac data at step 430. Finally, position information is obtained at step 440 by using the satellites indicated in the almanac data.

Navigation Message

The navigation message of a satellite can cause a problem for indoor receiving. This is due to the interaction between the correlation code of a satellite and the navigation message broadcast by the satellite. Each satellite broadcasts a high frequency signal (e.g. 1 MHz) of 1's and 0's. This signal is called the correlation code and is a pseudo random string of digital data that repeats at a high bit rate. The navigation message is also a digital message that is broadcast at a much lower bandwidth, several orders of magnitude slower than the correlation data rate. In one implementation, the navigation data is inserted into the correlation data stream as a series of inversions of the correlation data string. For example, a noninverted correlation data string could represent a digital 1 while an inverted correlation data string could represent a digital zero. Thus, for every 100,000 bits of correlation data (when a correlation data string is 100,000 bits in length), only a single navigation message bit is sent.

The operation of this system is illustrated in the flow diagram of Figure 6. At step 600, the satellite transmits the correlation code signal string to Earth, inverting it periodically to represent navigation message data bits. The target receiver receives the signal from space and the navigation message data from a terrestrial broadcast station at step 610. At step 620, the receiver correlates the data from the satellite. At decision block 630, the receiver uses the navigation message data from the terrestrial broadcast station to determine if an inversion of the navigation signal is about to occur. If no, the receiver continues correlating the signal at step 620. If yes, the receiver inverts the incoming correlation signal at the appropriate transition time at step 640 so that there is no loss of correlation due to data inversion. The system continues correlating at step 620.

The broadcast station should be relatively close, less than 100 miles away for instance, so that they receive essentially the same signal from the satellite. Using the string sent from the broadcast station, the target receiver is able to know when the inversions will occur, look for the inversions, and hence, the navigation message, while at the same time continuing to correlate on the weak signal.

Assistance Signal Architecture

An example of an architecture that may be used to transmit assistance signals is shown in Figure 7. A positioning system antenna 700 receives a satellite signal and transmits it to a positioning system radio frequency (RF) part 710. RF part 710 might

that is not completely transient in nature (i.e., Ephemeris data) and transmit it later to the receiver logic unit 735 when needed.

Embodiment of a Positioning System

One embodiment of a positioning system according to the present invention is illustrated in Figure 8. An assistance receiver 812 is coupled to an antenna 811. The assistance data receiver 812 provides navigation bits, Doppler frequencies, time synchronization, ephemeris data, base station coordinates for 1 ms ambiguity resolution, and pseudo-range differential corrections to a local broadcast network that may be wired, wireless, cellular, or network or internet based.

The SPS receiver in the embodiment of Figure 8 comprises an antenna 801 coupled to a processing block 802. The output of processing block 802 is coupled to A/D converter 803 and memory 804 to difference node 805. The output of node 805 is coupled to filter block 806 along with data from the assistance receiver 812. Filter block 806 is coupled to accumulation block 808 and through iteration block 809 to ambiguity resolution block 810.

The output of memory 804 is also coupled to correlation and tracking block 813 which provides output to difference node 805 and to navigation data decoding block 814. The output of block 814 is coupled to memory 816 and to position

filter block 806 is applied to non-coherent accumulator 808 which performs a non-coherent detection and accumulation. The non-coherent detection computes some function of the modulus of the output of block 806. The two functions are the modulus and the modulus squared in one embodiment. Typical coherent integration times are on the order of 100 mSec. Non-coherent accumulation would typically be performed on data corresponding to a one second interval of the received signal.

The output of the cross-coherent accumulator is applied to block 809 that iteratively estimates the sub-millisecond pseudorange to the satellite in question. The pseudorange is ambiguous at the one mSec level. It is the function of ambiguity resolution block 810 to resolve the millisecond ambiguity in the pseudorange in a conventional manner. Block 810 takes as its inputs distances to satellites from a position computation performed at computation block 815.

Assistance data from the aiding receiver 812 communicates the navigation message bits, i.e., telemetry data, Doppler information, base station coordinates for 1 ms ambiguity resolution, PRN numbers and time synchronization information to the filter matched to the C/A and navigation message bits at filter block 806. The aiding SPS receiver also communicates ephemerides and differential corrections (if implemented) to the position computation block 815. Ephemerides may be stored in memory 816 for later use if desired.

Three points merit special mention at this point. First, the signal correlation and tracking module 813 does not work independently of the filter matched to the C/A code and navigation message bits (block 806). This is because the SNR of the received signal may be inadequate to allow the received signal to be tracked. By operating on the stored data, the causality requirement of the tracking loops is eliminated. Second, this technique does not compute the full cross-correlation function between the data and the locally generated signals. This is because the correlation coefficients are not computed for the uninteresting lags.

Finally, the data memory size can be reduced to the size necessary to store an amount of data that corresponds to the coherent integration period. If, after processing the first data set it is determined that additional data is needed, additional data may be required and stored in memory 804, processed, and the processed results combined with the results of the first processing results for improved accuracy or strength of a statistical test. Similarly, any number of subsequent samples may be acquired, processed, and incorporated into the pseudorange measurements and position computation.

The output of the primary filter may be viewed as complex correlation coefficients between the data input to the matched filter. This output is applied to a second matched filter. If T denotes the sample period of the primary filter, the ideal matched secondary filter is given by Bracewell's triangle function, the zeros of which correspond to one C/A code "chip" (define), convolved with the baseband equivalent of the composite of filters in the receiver, sampled at an interval T. The purpose of this secondary filter is to improve SNR by the complex correlation coefficients prior to non-coherent detection and subsequent accumulation. Loosely, the secondary filter uses information in samples adjacent to the peak correlation coefficient to improve the SNR. More precisely, to maximize SNR, the complex correlation coefficients are applied sequentially to the filter which has as its impulse response the time-reverse, complex conjugate of the above described filter. Practically, this filter may be approximated by a binary approximation to the ideal response. Since both of these operations are linear, they could, of course, be combined in a single filter. However, to do so would result in a more complex implementation.

Thus, a low signal-to-noise ratio positioning system is described in conjunction with one or more specific embodiments. The invention is defined by the claims and their full scope of equivalents.

8. The system of claim 6 wherein said computing device is a personal digital assistant.

9. The system of claim 1 wherein said signals and said assistance signals are obtained via a computer network.

10. The system of claim 9 wherein said computer network is the Internet.

11. A method for using a positioning system comprising:

transmitting signals from one or more satellites;

transmitting an assistance signal from a broadcast station; and

receiving said signals and said assistance signal with a receiver.

12. The method of claim 11 wherein said assistance signal includes one or more Doppler frequencies for said satellites.

13. The method of claim 11 wherein said assistance signal includes one or more locations for said satellites.

14. The method of claim 11 wherein said assistance signal includes a list of one or more satellites that are currently available.

15. The method of claim 11 wherein said assistance signal includes one or more navigation bits in said signals from said satellites.

22. The computer program product of claim 21 wherein said assistance signal includes one or more Doppler frequencies for said satellites.

23. The computer program product of claim 21 wherein said assistance signal includes one or more locations for said satellites.

24. The computer program product of claim 21 wherein said assistance signal includes a list of one or more satellites that are currently available.

25. The computer program product of claim 21 wherein said assistance signal includes one or more navigation bits in said signals from said satellites.

26. The computer program product of claim 21 wherein said receiver is a computing device.

27. The computer program product of claim 26 wherein said computing device is a cellular phone.

28. The computer program product of claim 26 wherein said computing device is a personal digital assistant.

29. The computer program product of claim 21 wherein said signals and said assistance signals are obtained via a computer network.

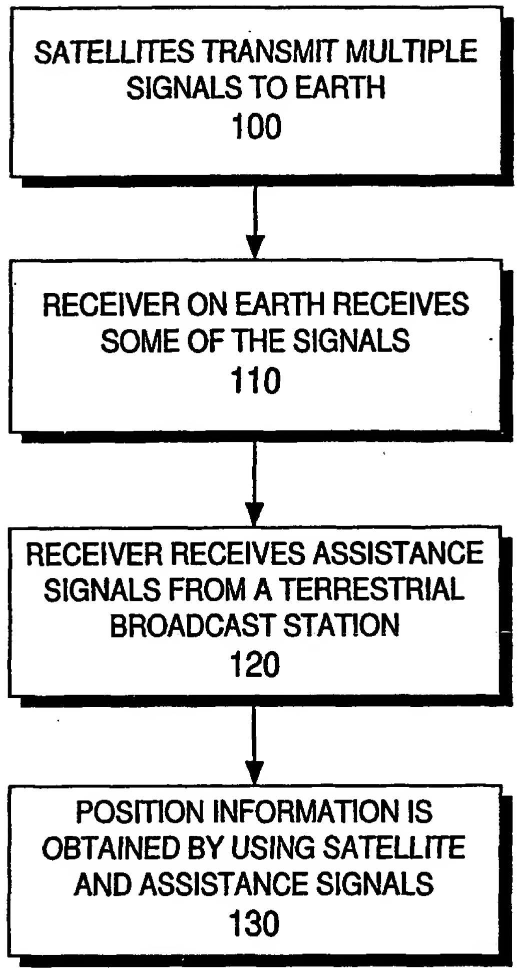

SATELLITES TRANSMIT MULTIPLE SIGNALS TO EARTH
100
RECEIVER ON EARTH RECEIVES SOME OF THE SIGNALS
110
RECEIVER RECEIVES ASSISTANCE SIGNALS FROM A TERRESTRIAL BROADCAST STATION
120
POSITION INFORMATION IS OBTAINED BY USING SATELLITE AND ASSISTANCE SIGNALS
130

FIGURE 1

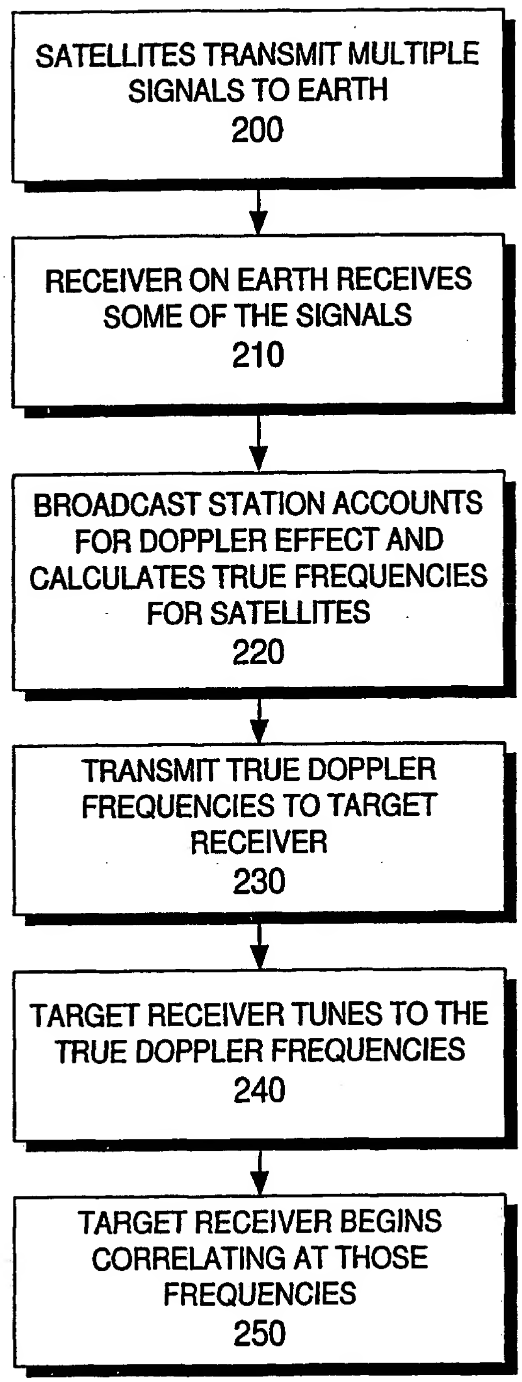

SATELLITES TRANSMIT MULTIPLE SIGNALS TO EARTH
200
RECEIVER ON EARTH RECEIVES SOME OF THE SIGNALS
210
BROADCAST STATION ACCOUNTS FOR DOPPLER EFFECT AND CALCULATES TRUE FREQUENCIES FOR SATELLITES
220
TRANSMIT TRUE DOPPLER FREQUENCIES TO TARGET RECEIVER
230
TARGET RECEIVER TUNES TO THE TRUE DOPPLER FREQUENCIES
240
TARGET RECEIVER BEGINS CORRELATING AT THOSE FREQUENCIES
250

FIGURE 2

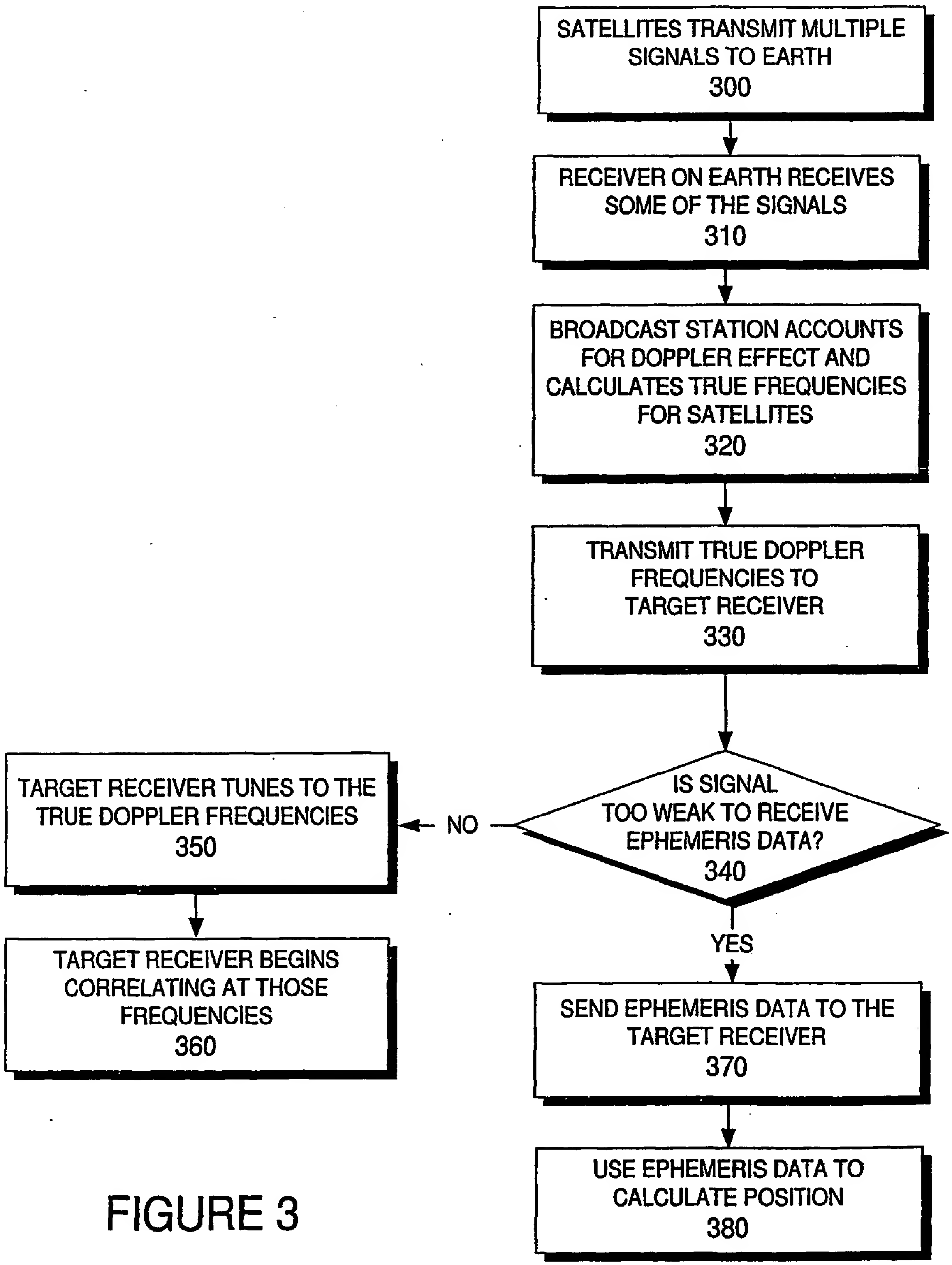

SATELLITES TRANSMIT MULTIPLE SIGNALS TO EARTH
300
RECEIVER ON EARTH RECEIVES SOME OF THE SIGNALS
310
BROADCAST STATION ACCOUNTS FOR DOPPLER EFFECT AND CALCULATES TRUE FREQUENCIES FOR SATELLITES
320
TRANSMIT TRUE DOPPLER FREQUENCIES TO TARGET RECEIVER
330
IS SIGNAL TOO WEAK TO RECEIVE EPHEMERIS DATA?
340
NO
TARGET RECEIVER TUNES TO THE TRUE DOPPLER FREQUENCIES
350
TARGET RECEIVER BEGINS CORRELATING AT THOSE FREQUENCIES
360
YES
SEND EPHEMERIS DATA TO THE TARGET RECEIVER
370
USE EPHEMERIS DATA TO CALCULATE POSITION
380

FIGURE 3

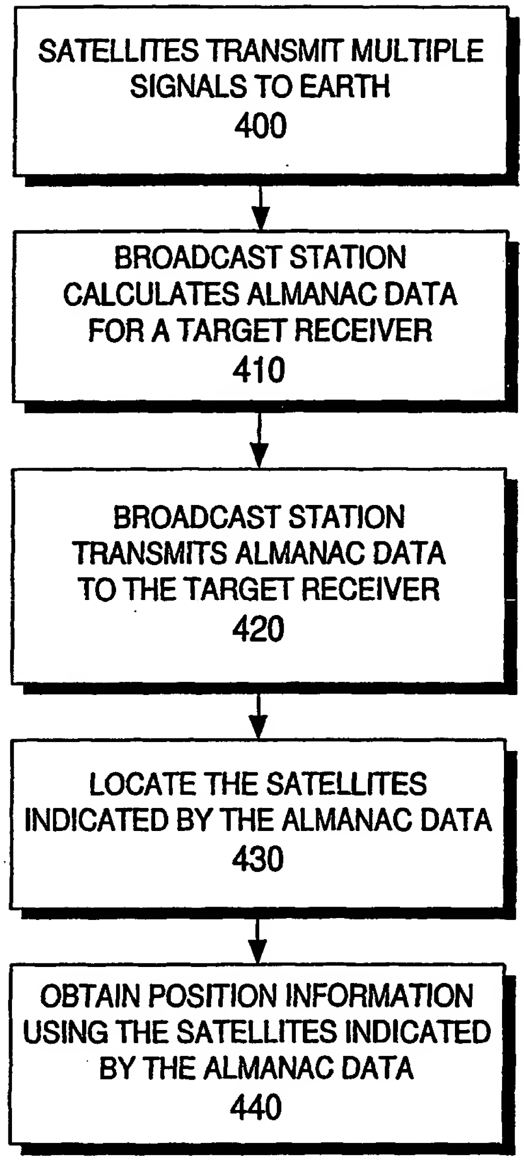

SATELLITES TRANSMIT MULTIPLE SIGNALS TO EARTH
400
BROADCAST STATION CALCULATES ALMANAC DATA FOR A TARGET RECEIVER
410
BROADCAST STATION TRANSMITS ALMANAC DATA TO THE TARGET RECEIVER
420
LOCATE THE SATELLITES INDICATED BY THE ALMANAC DATA
430
OBTAIN POSITION INFORMATION USING THE SATELLITES INDICATED BY THE ALMANAC DATA
440

FIGURE 4

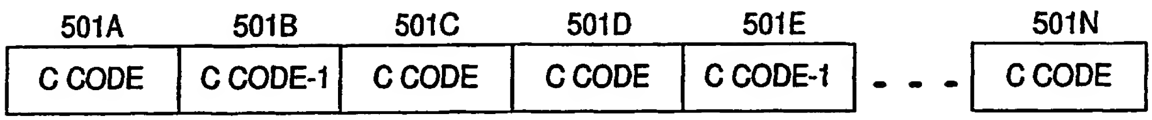

501A
501B
501C
501D
501E
501N
C CODE
C CODE-1
C CODE
C CODE
C CODE-1
C CODE

FIGURE 5

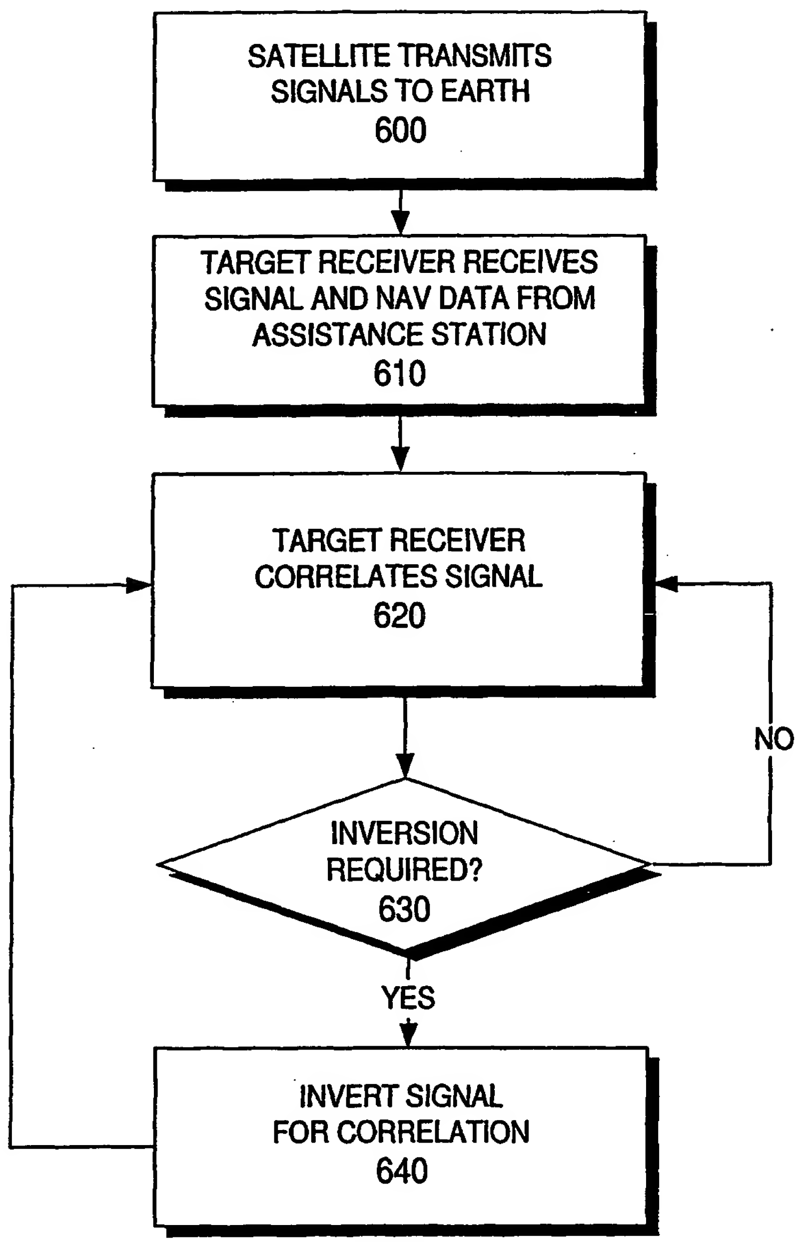

SATELLITE TRANSMITS SIGNALS TO EARTH
600
TARGET RECEIVER RECEIVES SIGNAL AND NAV DATA FROM ASSISTANCE STATION
610
TARGET RECEIVER CORRELATES SIGNAL
620
NO
INVERSION REQUIRED?
630
YES
INVERT SIGNAL FOR CORRELATION
640

FIGURE 6

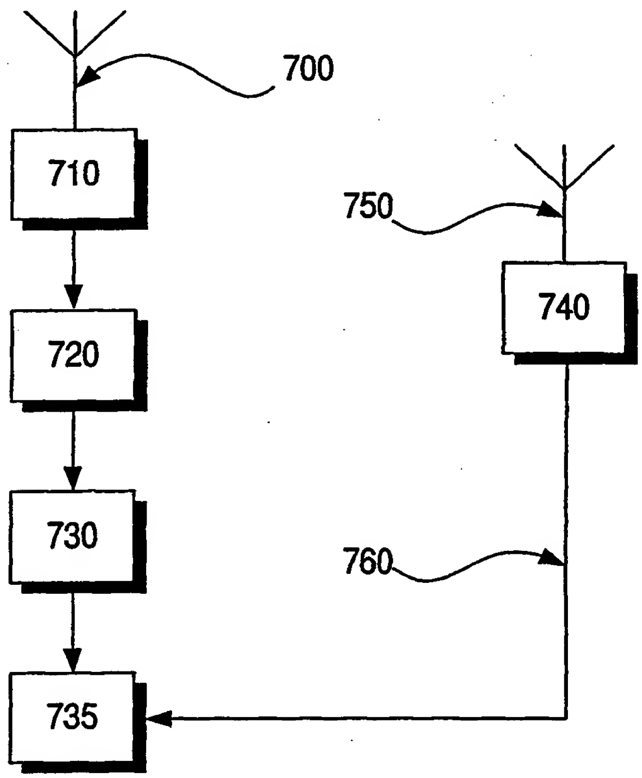
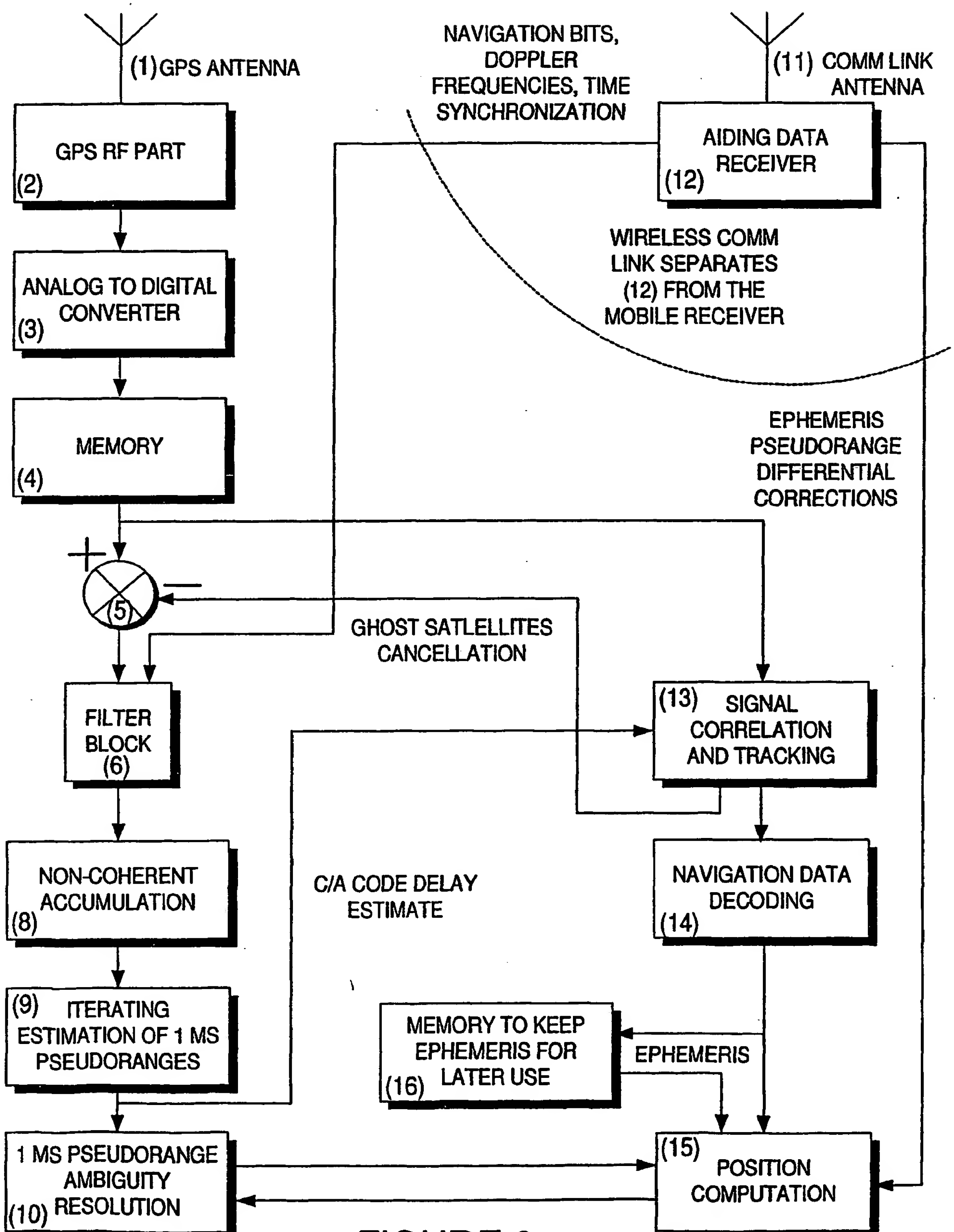


FIGURE 7



(1) GPS ANTENNA
GPS RF PART
(2)
ANALOG TO DIGITAL CONVERTER
(3)
MEMORY
(4)
(5)
FILTER BLOCK (6)
NON-COHERENT ACCUMULATION
(8)
(9) ITERATING ESTIMATION OF 1 MS PSEUDORANGES
1 MS PSEUDORANGE AMBIGUITY RESOLUTION
(10)
NAVIGATION BITS, DOPPLER FREQUENCIES, TIME SYNCHRONIZATION
(11) COMM LINK ANTENNA
AIDING DATA RECEIVER
(12)
WIRELESS COMM LINK SEPARATES (12) FROM THE MOBILE RECEIVER
EPHEMERIS PSEUDORANGE DIFFERENTIAL CORRECTIONS
GHOST SATLELLITES CANCELLATION
(13) SIGNAL CORRELATION AND TRACKING
C/A CODE DELAY ESTIMATE
NAVIGATION DATA DECODING
(14)
MEMORY TO KEEP EPHEMERIS FOR LATER USE
(16)
EPHEMERIS
(15) POSITION COMPUTATION

FIGURE 8